Finding the Mass Percent of Acetic Acid in Vinegar

PURPOSE

- Determine the mass percent and molarity of acetic (ethanoic) acid in household vinegar
- Standardize sodium hydroxide solution using a primary standard as a reference
- Compare two titration methods and their results with data on manufacturer's label

INTRODUCTION

"Vinegar is good wine gone bad," quipped Alton Brown, the TV food show host and science buff. Vinegar, its name derived from the old French word *vinaigre*—from the roots *vin* (wine) and *aigre* (sour)—is a dilute solution of acetic (ethanoic) acid, CH_3COOH or $HC_2H_3O_2$, a weak monoprotic acid. The acidity in vinegar is reduced by addition of water, so that the final acidity typically ranges from 3–7%, depending on the type of vinegar. Rice wine vinegar may have a 3% acidity, while red wine vinegars contain up to 7% acetic acid. The different varieties of vinegar also vary in their color: distilled white vinegar is clear and colorless with a 5% acidity, while balsamic vinegar is dark brown and has higher acidity.

Procedure Preview In this experiment, you will standardize a 0.5 *M* NaOH solution using a **primary standard.** A primary standard is a compound that is extremely pure and stable. Therefore, a known amount can be measured by mass and used with confidence to react with another compound or ion in a known reaction. The primary standard serves as a reference during a titration to help determine the actual concentration of some ion or compound in the solution being standardized. Potassium hydrogen phthalate ("KHP"), $KHC_8H_4O_4$, which is a weak, monoprotic acid, will be used as the primary standard since it reacts to neutralize sodium hydroxide in the reaction whose net ionic equation is:

$$HC_8H_4O_4{}^-{}_{(aq)} + OH^-{}_{(aq)} \rightarrow H_2O_{(l)} + C_8H_4O_4{}^{2-}{}_{(aq)}$$

You will then use this standardized solution to titrate a vinegar sample of known mass.

$$CH_3COOH_{(aq)} + OH^-{}_{(aq)} \rightarrow CH_3COO^-{}_{(aq)} + H_2O_{(l)}$$

The data collected from this titration will be used to determine the molarity of acetic acid as well as the percent by mass of acetic acid in that type of vinegar. These results can then be compared with values printed on the vinegar label.

Pre-Lab Questions

1. During storage, solid sodium hydroxide can become contaminated when it reacts with carbon dioxide gas from the atmosphere. Write the balanced net-ionic equation for this reaction.

2. A student wanted to make 0.75 liter of a 0.250 *M* solution of sodium hydroxide by diluting a 0.750 *M* standardized sodium hydroxide solution. Calculate the volume of the concentrated solution the student would need to use to make this dilute solution. What volume of water must be added? Assume volumes are additive.

Pre-Lab Questions *(continued)*

3. The student then used the 0.250 M solution to titrate 0.0500 L of a phosphoric acid sample. The student's data were:

   Initial buret reading: 14.00 mL

   Final buret reading: 26.50 mL

   a. Write a balanced chemical equation describing this reaction.

   b. Calculate the concentration of this sample in moles per liter.

4. Once a bottle of vinegar is opened and used regularly, it loses its acidity over time. Can you remember the smell of vinegar? Explain why the acidity of vinegar decreases over time when the bottle is used regularly.

Titration Method Using a 2-mL Microburet

MATERIALS

- 2-mL microburet *(see Appendix B)*
- buret clamp and buret stand
- 24-well microplate
- white paper
- phenolphthalein solution
- potassium hydrogen phthalate solution (~9 g potassium hydrogen phthalate/250.0 mL solution)
- ~0.5 M NaOH
- microstir bars *(see Appendix C)*
- magnetic stirrer
- vinegar sample(s)

PROCEDURE

I. Preparing the microwell plate

Step A Measure the mass of a clean, dry 24-well microplate.

Step B Add a micro-stir bar to a numbered well and measure the mass of the microwell plate. Record both the mass and the well number.

Step C Repeat step B, putting a stir bar in a different well.

Step D Add 1.00 mL of vinegar from buret into first well and then record the mass.

Step E Repeat step D for second well.

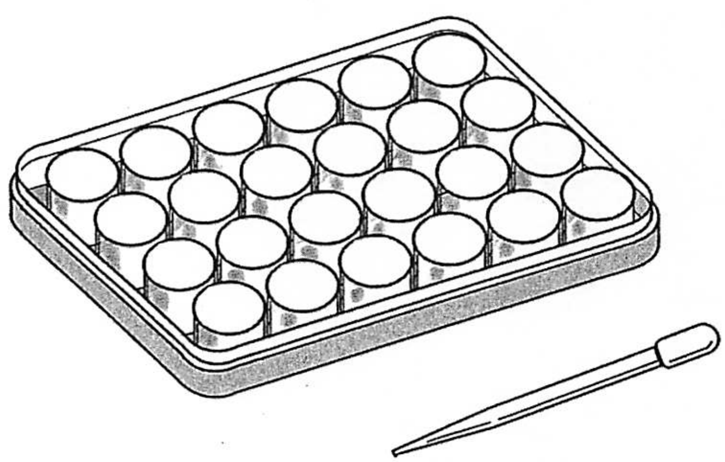

Figure 8.1 For experiments demanding a series or comparison of reactions, a well-plate and microburet or small-volume pipet may be most suitable.

PROCEDURE
(continued)

II. Standardization of sodium hydroxide solution

Step A Add 1.00 mL of potassium hydrogen phthalate solution to two different microwells, recording each well number and exact volume added to it. Also **record exact concentration of this solution.**

Step B Record the concentration of the potassium hydrogen phthalate solution.

Step C Add 1 drop of phenolphthalein solution and micro-stir bar to each well.

Step D Place a sheet of white paper on a magnetic stir plate, then place microwell plate on magnetic stirrer with well to be used in center of plate. Turn on magnetic stirrer so that the micro-stir bar slowly rotates and mixes the vinegar sample in the well to be titrated.

Step E Fill microburet with the sodium hydroxide solution to be standardized and rinse microburet twice with the sodium hydroxide solution.

Step F Record actual concentration of sodium hydroxide solution and initial volume of the base to the 0.001 mL.

Step G Titrate sample to the endpoint noted when phenolphthalein turns light pink. Record final volume.

Step H Repeat Steps D–G for the second sample of potassium hydrogen phthalate.

III. Analysis of vinegar sample

Step A Add 1 drop of phenolphthalein solution to each well containing vinegar.

Step B Place a sheet of white paper on a magnetic stir plate, then place the microwell plate on a magnetic stirrer with the well to be used in center of plate. Turn on the magnetic stirrer so that the micro-stir bar slowly rotates and mixes the vinegar sample in the well to be titrated.

Step C Fill microburet with standardized sodium hydroxide solution and rinse tip.

Step D Record actual concentration of sodium hydroxide solution and initial volume of the base to the 0.001 mL.

Step E Titrate sample to the endpoint noted when phenolphthalein turns light pink. Record final volume.

Step F Repeat Steps B–E for second vinegar sample.

Calculations

1. Calculate the moles of potassium hydrogen phthalate in each sample titrated.
2. Calculate the molarity of sodium hydroxide for each sample, then calculate the average molarity of sodium hydroxide.
3. Calculate the mass of vinegar in each sample titrated.
4. Calculate the moles of acetic acid in each vinegar sample using your titration data.
5. Calculate the mass of acetic acid in each vinegar sample.
6. Calculate the percent by mass of acetic acid in each vinegar sample.
7. Compare your results to the value stated by the manufacturer on the label of the vinegar container. Calculate the percent error in your results for each vinegar sample.
8. Calculate the average molarity of acetic acid for each type of vinegar analyzed.

Post-Lab Questions

1. Compare your average percent by mass of acetic acid to the value printed on the label of the vinegar bottle. Comment briefly on any similarities and differences.

2. Can this procedure be used to determine the acidity of dark brown balsamic vinegar? Explain your answer.

3. In the procedure using the 50-mL buret, you added about 15 mL of distilled water to the flask. Does the exact volume of water added affect your experimental results? Explain your answer.

4. In the procedure using the 50-mL buret, you measured the mass of potassium hydrogen phthalate added and dissolved this mass in distilled water. What would happen to the calculated mass percent of acetic acid in vinegar if some solid potassium hydrogen phthalate remained undissolved when the indicator turned pink and you ended your titration? Explain in detail.

5. In the microtitration experiment, the mass of the microwell plate and microstir bar was measured after the mass of the microwell plate was measured, but before any vinegar sample was added. If a student forgot to measure this mass, how would the percent by mass of acetic acid in vinegar be impacted? Explain your answer in detail.